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Original Article

# Modeling and Assessing the Consequences of Oil Pipeline Leakage Using PHAST Software: A Case Study; Jarahi River in Southwest of Iran

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**Abstract**

**Background:** This study models the consequences of oil pipeline leakage using PHAST software, focusing on a segment crossing the Jarahi River in Southwest Iran. The goal is to understand potential environmental and safety impacts, establish safe zones for different leakage scenarios, and suggest strategies for risk mitigation.

**Methods:** High-risk factors were identified through Failure Mode and Effects Analysis (FMEA). Consequences of pipeline leakage were simulated in PHAST software under varied scenarios, considering factors such as gap size, seasonal weather conditions, and location. This approach enabled assessment of safe distances in case of fire, explosion, or release of toxic substances.

**Results:** Leakage consequences varied by gap size and seasonal conditions. For example, a 200-mm pipeline gap produced maximum substance concentrations of 160,860 mg/L in summer and 166,695 mg/L in winter. Safe distance thresholds also differed; in winter, the safe distance was 275 m, while in summer it reached 520 m. Radiation and blast wave intensities were higher in winter due to environmental stability, indicating greater risks.

**Conclusion:** PHAST software proves valuable in modeling pipeline leakages and determining safety perimeters. The findings highlight the need for ongoing risk management, especially in sensitive areas like the Jarahi River. Routine safety inspections and enhanced environmental safeguards are recommended to minimize potential hazards and protect surrounding ecosystem

**Keywords:** Modeling, River pollution, Leakage, Environment

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## Introduction

Energy serves as the cornerstone of the modern world, with fuels, particularly fossil fuels, representing a primary means of energy supply. Petrochemicals, including crude oil, are extensively utilized across various industries.[1-3] The transportation of these materials is a vital component of the energy supply chain.[4,5]

The need for efficient material transportation becomes increasingly crucial with the expansion of different industries.[6] Crude oil can be transported through various methods, including road, rail, pipeline, and ship.[7-9] However, the proximity of these pipelines to inhabited areas or water sources heightens concerns, as accidents could lead to irreversible environmental damage.[10,11] Despite advancements in pipeline technology, accidents in this sector have been observed. Risk management refers to the effective application of policies, resources, regulations, and guidelines to assess and control existing risks.[12-15] This process aims to reduce risks that could impact transmission line workers, the environment, and the public.[16-19]

Risk assessment, a key component of the overall risk management process, is based on defining risk. Risk is defined as the likelihood of an accident occurring and the severity of its consequences.[20] Similar to other industries, pipelines can undergo risk assessment using qualitative and quantitative models.[21] The availability of information about the pipeline significantly influences the model's application. Ultimately, after evaluating pipeline risks, appropriate decisions can be made to prevent accidents and address maintenance and repair issues.[22] Decisions in oil, gas, and petrochemical companies are not only aimed at accident prevention but also at pipeline route selection, pipeline ranking, and the evaluation of risk reduction strategies. Therefore, considering the presence of petroleum materials and energy in these industries and modeling the potential negative consequences of explosions, fires, and toxic substance releases are crucial.[23,24] Consequently, one of the critical stages of risk assessment that safety engineers must undertake is modeling the consequences of potential accidents in a processing unit.[25] Modeling involves simulating the release of substances into the environment, followed by simulating the effects of toxicity, ignition, or explosion of these substances.[26] The PHAST model is the most widely used and potent software for HSE specialists in the oil, gas, and petrochemical industries.[27,28] PHAST models incidents such as fires and explosions of reservoirs and pipelines and graphically presents the findings, including the impact range. Emergency response planning and risk assessment heavily rely on these findings.[29]

The Maron oil and gas exploitation company is responsible for oil and gas production, processing, transmission, as well as maintenance, repairs, and optimization of associated facilities and pipelines. The Jarahi River, one of the major rivers in the catchment basin of the Persian Gulf and the Oman Sea, falls within the operating area of the Maron oil and gas exploitation company and is thus susceptible to numerous environmental risks. This study aims to model and assess the effects of a 36” main oil pipeline leak passing through the Jarahi River. The objective of this investigation was to model and assess the risk of a pipeline leakage occurring over the Jarahi River. To achieve this, information from the field of risk identification and assessment using the failure modes and effects analysis (FMEA) method was utilized to identify high-priority risks. These findings were subsequently compared to the pipeline’s qualitative risk assessment.

## Materials and Methods

The effects of the leakage were then modeled using PHAST software. Following this, various scenarios were defined to anticipate potential outcomes after analyzing the identified risks, with a focus on scenarios related to pipeline breakage and material discharge. Detailed descriptions of these scenarios were provided, along with instructions on how to use the PHAST software to simulate their consequences. Additionally, the study area was thoroughly investigated.

### *RPN Calculation*

The risk priority number is the result of three numbers: severity (S), occurrence (O), and probability of detection (D).[30]

$$RPN = S \times O \times D.$$

The risk priority number ranges from 1 to 100.

A committee should be established to reduce high-risk numbers through corrective measures.

In this study, the risk priority number was employed to rank the risks in this step, and an RPN limit was taken into consideration based on the FMEA system’s assessment. For instance, according to Tables 1-3, the limit for the 90% confidence level is as follows:

Roads, rivers, villages, agricultural lands, and forests are among the significant dangerous locations along this pipeline’s route. Using Table 4, each risk factor’s consequences in each section have been listed in the

**Table 1.** High-Priority Risks in Risk Assessment by the FMEA Method

| Name of the activity | Potential hazard | Cause of danger | Occurrence | Consequence | Primary risk assessment (RPN) |
|---|---|---|---|---|---|
| Pipeline welding with positive fluid flow | $H_2S$ gas | Leakage (line puncture) | Fire | Death | 90 |
| Pipeline welding with positive fluid flow | Gas | Leakage (line puncture) | Fire | Death | 120 |
| Pipeline welding with positive fluid flow | NGL gas condensate | Leakage (line puncture) | Fire | Death | 90 |
| Pipeline welding with positive fluid flow | Oil | Leakage (line puncture) | Fire | Death | 108 |
| Pipeline welding with positive fluid flow | Oil and gas and other fluids | Decrease or increase in fluid pressure | Explosion | Death | 120 |
| Pipeline sandblasting | Oil and gas and other fluids | Line exhaustion and high-pressure sandblasting, and line perforation | Fire | Death | 120 |
| Pipeline pressure assessment | Cold fluids | Increased pressure | Burst in the pipe | Death | 96 |
| Pipeline pressure assessment | Hazards caused by fluid pressure inside the pipe | Pipe exhaustion and pressure intolerance | Burst in the line | Death | 160 |
| Pipeline pressure assessment | Hazards caused by fluid pressure inside the pipe | Human error (using connections with inappropriate pressure class) | Burst in joints | Death | 160 |
| Pipeline repair operations in special conditions (such as earthquakes, bombings, etc.) | Oil and gas | Burst in the lines | Fire and explosion | Death | 126 |

**Table 2.** Threats and Major Risk Factors in the 36" Main Oil Pipeline From Maron 3 to the Jarahi river

| Parameters | Consequence |
|---|---|
| Human intervention | Collision of machinery with pipelines, vandalism, breach of privacy |
| Corrosion | External and rarely internal corrosion |
| Design, installation, and operation errors | Non-standard alloys, inappropriate selection of welding seam and coating, inappropriate installation methods, inappropriate operation of safety and control equipment, and human 8error in management. |
| Natural hazards | Floods, landslides, earth leaks, earthquakes |

following order.

The risk matrix for the 36” main oil pipelines from Maron 3 to the Jarahi river for the main high-risk areas has been specified in Table 5, based on the severity specified in the table for each consequence and the probability of threats occurrence.

Steps for using the PHAST software to model and assess the effects of an oil pipeline leakage:

*Step 1:* Determining the Consequences of Objective Assessments: The goal of modeling and assessing the consequences in this study was to determine the potential risks of pipeline leakage, the maximum distance of oil discharge, and the pipeline’s safe distance.

*Step 2:* Explanation of the investigated process unit: Maron Oil and Gas Exploitation Company is in charge of producing, processing, and transporting oil and gas, as well as maintaining, repairing, and optimizing related facilities and pipelines. As one of the subsidiary companies of the National Iranian South Oil Company, this company began operations on March 20, 2000, producing approximately 600 000 barrels of oil per day from a total of 264 production wells.

The company’s geographical area is bordered to the north by Haftgol and White Oil, to the east and southeast by the Jarahi River, and to the west and southwest by the operational area of the Karun Oil and Gas Exploitation Company. This area is located 30 kilometers from Ahvaz and encompasses the Maron, Kopal, and Shadgan fields, covering an area of 1370 km$^2$.One of the significant permanent rivers in the catchment basin of the Persian Gulf and the Oman Sea is the Jarahi River, situated within the operating area of the Maron Oil and Gas Exploitation Company. Originating from the Yasouj Mountains, this river spans approximately 438 km and passes through the cities of Kohgiluyeh, Behbahan, Ramhormoz, Bandar Mashehr, Shadgan, and Khorramshahr. Primarily flowing through Khuzestan, the Jarahi River eventually enters the Shadgan Plain and merges with the Karun River before reaching the Persian Gulf.

The current investigation aims to model and assess the consequences of a spillage from the 36” main oil pipeline that crosses over the Jarahi River. This pipeline spans the distance between Ahvaz and Omidiyeh, covering a distance of 85 km from Ahvaz to the Meshrage section, passing above the Meshrage crossing bridge. Within the research region of this investigation, less than one kilometer of the pipeline intersects with the Jarahi River. The height of the pipeline above the river level is determined by the flow

**Table 3.** Ranking the Probability of Occurrence of Threats in the 36" Main Oil Pipeline From Maron 3 to the Jarahi River

| | **Probability of Threats Occurrence** |
|---|---|
| Very Unlikely | Consequence |
| Unlikely | Impacts of adjacent pipelines, inappropriate installation methods, non-standard alloys, improper choice of weld seam and coating |
| Possible | Sabotage operations, human error in line management, the collision of machinery with pipelines |
| Likely | Flooding, inappropriate operation of safety and control equipment |
| Very Likely | Corrosion, violation of privacy |

**Table 4.** The Severity of the Consequences of the Occurrence of Threats Based on Their Location in the 36" Main Oil Pipeline From Maron 3 to the Jarahi River

| **Risk Factors** | **Locations** | | | |
|---|---|---|---|---|
| | **Main and Subsidiary Roads** | **River** | **Agricultural Land and Forest** | **Village** |
| Sabotage operations, human error in line management, the collision of machinery with pipelines | 5 | 5 | 5 | 5 |
| Corrosion and violation of privacy | 5 | 5 | 5 | 5 |
| Flooding, inappropriate operation of safety and control equipment | 3 | 5 | 3 | 3 |
| Impacts of adjacent pipelines, inappropriate installation methods, non-standard alloys, inappropriate selection of weld seam and coating | | 5 | 4 | 5 |

**Table 5.** Probability of Occurrence

| | | | | | | |
|---|---|---|---|---|---|---|
| **Consequence intensity** | 5 | - | River and village | River, village, road, and agricultural lands | River | River, village, road, and agricultural lands |
| | 4 | - | Road and agricultural lands | - | - | - |
| | 3 | - | - | - | Village, road, and agricultural lands | - |
| | 2 | - | - | - | - | - |
| | 1 | - | - | - | - | - |
| | | 1 | 2 | 3 | 4 | 5 |
| | | - | Impacts of adjacent pipelines, inappropriate installation methods, non-standard alloys, and inappropriate selection of weld seam and coating | Sabotage operations, human error in line management, the collision of machinery with pipelines | Flooding, inappropriate operation of safety and control equipment | Corrosion, and violation of privacy |
| | | | **Occurrence probability** | | | |

**Table 6.** General Information of the 36" Main Oil Pipeline From Maron 3 to the Jarahi River

| The name of the Pipeline | Origin | Destination | Length (km) | Thickness (mm) | Coverage Type | Coverage Quality | Installation Year | Maximum Operating Pressure (Psi) |
|---|---|---|---|---|---|---|---|---|
| Main 36" for oil | Maron 3 | Omidiyeh booster | 18 | 9.53 | PVC | Weak | 1350 | 300 |

rate of the river, as indicated in Table 6. The pipeline itself is 18 km in length, with 107 m crossing over the river. To conduct the assessment, we will utilize the LONG PIPE LINE equipment in the PHAST software, adhering to the TOTAL GS 253 standard and the Norwegian DNV standard for pipeline protection risk assessment.

1. The level of the opening developed in the scenario under consideration should be at least 20% of the size of the pipeline's cross-section.
2. The desired pipeline length-to-diameter ratio should be greater than 300.

The pipeline's length is estimated at 300 meters due to the small scale of the map. Its operational temperature is 95 °F, with an operating pressure of 350 psi. Additionally, the pipe section transports 593,000 pounds of process material per hour. Assuming the fluid is crude oil, its composition would be approximately 70% methane, 10% ethane, 7% propane, and 13% hexane (as detailed in Table 7).

Summer weatsher conditions include a wind speed of 6.5 m/s, a humidity of 60%, stability of E, and a temperature of 41 °C.

*Step 3:* Risks identification: Any factor that can potentially cause harm, including raw materials, machinery, working procedures, etc., can be categorized as a risk.

Identifying risks thus refers to the process of recognizing the presence of risk and specifying its features.

Both routine and unusual operational conditions, as well as potential emergency situations and events, must be taken into account when identifying risks. The oil and gas industry is fraught with persistent potential risks that could result in significant and irreversible financial and environmental harm. Accurately identifying these risks and effectively managing them is essential to enhance safety and reduce the likelihood of accidents in the industry. One of the following methods can be used to identify process risks:

1. Safety review
2. Checklist analysis
3. Question analysis
4. Analysis of the ingredients in the oven

*Step 4:* Scenario determination and analysis: At this point, three gap scenarios have been considered for the investigated pipeline section:

1. Gap 200 mm
2. Gap 300 mm
3. Gap 400 mm

*Step 5:* Consequence modeling: With the assistance of consequence modeling, it becomes feasible to assess the effects of an incident and any associated events at any location and time. These outcomes enable the estimation of the severity of the accident and its impact on the destruction of material resources, such as buildings and machinery, across various times and locations. Consequently, consequence modeling involves employing mathematical models to predict the effects and outcomes of the release and dispersion of a substance in the environment.

**Table 7.** Characteristics of Crude Oil

| Component | Mass Amount |
|---|---|
| Methane | 70 |
| Ethane | 10 |
| Propane | 7 |
| N-Hexane | 13 |

The consequence modeling process is generally divided into several stages, commencing with discharge modeling. The output of discharge modeling is then utilized as input data in emission modeling. Considering the weather conditions of the area under examination, the height of the material release point, the direction of discharge, and the physical properties of the substance being released, modeling the release and subsequent consequence modeling—such as modeling fire, explosions, and the dissemination of toxic substances—will be evident as outputs of the PHAST software. Consequently, the representation of the distribution or spatiotemporal profile of radiation intensity, explosion waves, and toxic substance concentrations will be available as the final outcomes of modeling with PHAST software.

To begin modeling with PHAST software, it is necessary to initially determine the characteristics of the emission source. This includes identifying the type of material and the operating parameters of the preferred equipment, such as temperature and pressure.

*Scenario selection:* Once the properties of the materials involved in the process have been determined, the type of probable scenario should be selected.

### *Conditions Analysis*

*Location:* Data related to the location of the leakage occurrence is one of the influencing factors in the modeling results. This includes determining the height, north, and south coordinates based on the coordinates' point of origin and location on the map. Additionally, in the case of liquid leakage, the size and nature of the liquid pool should be established.

*Weather conditions:* Determining the weather conditions and their related parameters is a modeling requirement, as the type of weather conditions can impact the outcomes of accident modeling.

The desired meteorological data for PHAST software modeling include:

- Air and ground temperature
- Humidity
- Wind speed and direction
- Geographical conditions

If local weather data is unavailable, the software defaults to using its preset weather conditions.

- Import data into PHAST software
- Incident modeling
- Damage assessment

## Results and Discussion

First scenario: A location-specific breach scenario for a 200-mm gap.

The graph illustrates that the peak concentration, occurring at a distance of 12 m from the pipeline gap during summer, reaches 160 860 ppm. Similarly, in winter, at the same distance of 12 m, the maximum concentration peaks at 166 695 ppm. This indicates that during winter, when wind speeds are lower and stability is higher, the maximum concentration of the material at a specific point is higher compared to summer conditions (Figure S1).

Additionally, according to the concentration vs. time graph, it can be inferred that during summer, the substance's concentration remains constant from the 5th second onwards. However, in winter, due to environmental stability and low substance dispersion, the concentration decreases after 30 seconds, particularly at a distance of 50 m. Summer conditions facilitate the dispersion of the substance over longer distances and durations, resulting in a broader impact area with a sustained concentration (Figure S2).

The JET FIRE event, involving a 200 mm pipeline gap, is depicted in the graph. During summer, radiation up to a maximum rate of 310 kW/m² is expected at distances ranging from 44 to 57 m. In winter, this radiation increases to 332 kW/m² between distances of 46 to 58 m. It is noteworthy that the maximum solar radiation reaching the earth is typically around 1.5 kW/m², underscoring the significance of these radiation levels. Notably, ambient air temperature has a more pronounced effect on JET radiation during winter compared to summer (Figure S3 and Table S1).

The graph illustrates that radiation is not limited to one direction (in line with the wind), but can also occur in the opposite direction. Moreover, in the presence of a spark source and uniform dispersion of the gas cloud throughout the environment, a flash fire or sudden fire can ensue. For the 200 mm pipeline gap, such a fire would manifest in three dimensions, extending up to a radius of 389 m in summer and 288 m in winter (Figure S4 and S5).

According to the graph depicting the maximum pressure wave by distance, a maximum pressure wave, or "Blast Wave," with a pressure of 19.7 bar will occur at a distance of 275 m from the pipeline in winter. In summer, the maximum pressure wave will occur at a distance of 374 m with a pressure of 18 bar. The faster time of maximum pressure in winter compared to summer is attributed to the more stable weather conditions. Undoubtedly, the pressure wave decreases as the effective distance from the process incident source increases (Figure S6 and Table S2).

Furthermore, during summer, we can feel the pressure wave up to 654 m in the x direction from the source. This sensing range applies to the winter pressure wave up to a distance of 560 m in the x direction from the source. Additionally, the pressure wave's effective radius will be larger during winter. In this instance, the reference pressure wave is 0.02 bar, and it can be sensed up to these distances (Figure S7).

### *Second Scenario: Location-Specific Breach Scenario* for a Gap of 300 mm

We can infer from the graph of maximum concentration versus distance that we will experience a concentration of 204 700 ppm in the summer at a distance of 11 m (graph peak). Additionally, at a distance of 11 m, we will experience a maximum concentration of 214 700 ppm during winter. Thus, the higher the maximum concentration of the material at a given point, the lower the wind speed and the higher the stability. Wind speed is lower and stability is higher in winter than in summer. The maximum concentration is depicted in two graphs at nearly identical distances (Figure S8).

Furthermore, based on the concentration vs. time graph, it is possible to deduce that during the summer, from the 4th second onwards, the concentration of the substance in the environment remains unchanged. In winter, however, the concentration of the substance in the environment is constant after 15 seconds. After 1141 seconds in both weather conditions, the material's concentration in the environment decreases (Figure S9).

The graph indicates that during the summer, we will experience radiation from a distance of 59 to 79 m at a maximum of 338 kW/m². From a distance of 61 to 75 m, this radiation will be 350 kW/m² during wintertime. When comparing winter and summer JET radiation, ambient air temperature is an important factor. The maximum radiation distance increases as the gap diameter increases (Figure S10 and Table S3).

In the presence of a spark source, the gas cloud will also disperse homogeneously in the environment, resulting in a flash fire or a sudden fire. In the summer, this fire will develop up to a radius of 523 m, and in the winter, up to a radius of 490 m, for the 300 mm gap of the pipeline in three dimensions (Figure S11).

A maximum pressure wave, or "Blast Wave," with a pressure of 19.7 bar, will occur at a distance of 473 m from the pipeline in the winter, according to the graph depicting the maximum pressure wave by distance. In the summer, the maximum pressure wave will occur at a distance of 520 m, with a pressure of 19.7 bar. Despite the difference in distance at which the maximum pressure wave occurs, the magnitude of this wave is the same in both summer and winter for the 300 mm gap. The disparity in distance is attributed to environmental temperature conditions, expansion, and contraction, resulting in pressure changes within the pressure wave profile (Figure S12 and Table S4).

### *Third Scenario: Location-Specific Breach Scenario for a Gap of 400 mm*

From the graph depicting the maximum concentration versus distance, it can be inferred that during the summer, at a distance of 11 m (the graph's peak) from the pipeline gap, we will experience a concentration of 219 900 ppm. Similarly, in winter, at the same distance of 11 m, the maximum concentration will be 232 500 ppm. This suggests that the higher the maximum concentration of the material at a given point, the lower the wind speed and the higher the stability. Notably, wind speed is lower and stability is higher in winter compared to summer. The maximum concentration is depicted in two graphs at nearly identical distances (Figure S13).

Moreover, analyzing the concentration vs. time graph reveals that during the summer, the concentration of the substance in the environment remains constant from the third second onwards. Similarly, in winter, the substance concentration remains unchanged after 10 seconds. Notably, the decreasing trend of the material's concentration is disregarded in both weather conditions (Figure S14).

The graph illustrates that during the summer, radiation will be experienced at a distance ranging from 62 to 83 m, with a maximum intensity of 343 kW/m². Conversely, during winter, radiation intensity of 350 kW/m² will be observed at a distance of 65 to 80 m. Comparing winter and summer JET radiation, ambient air temperature emerges as a crucial factor. Notably, the maximum radiation distance increases with the gap diameter (Figure S15 and Table S5).

In addition, if there is a spark source and the gas cloud disperses uniformly throughout the environment, a flash fire or sudden fire will ensue. During summer, this fire will develop in three dimensions up to a radius of 575 m, while in winter, it will extend to a radius of 543 m for the 400 mm pipeline gap (Figure S16).

The graph depicting the maximum pressure wave by distance indicates that the BLAST WAVE, with a pressure of 19.7 bar, will occur in winter at a distance of 537 m from the pipeline. In the summer, the maximum pressure wave will occur at a distance of 566 m, also with a pressure of 19.7 bar. Despite the difference in distance at which the maximum pressure wave occurs, the magnitude of this wave remains consistent between summer and winter for the 300 mm gap. The disparity in distance is attributed to environmental temperature conditions, resulting in expansion and contraction, and consequently, pressure changes in the pressure wave profile (Figure S17 and Table S6).

### *Comparison of Consequences in Various Scenarios*

The maximum emission concentration at a given distance is observed with a 400 mm gap in winter, reaching a concentration of 232 500 ppm at 11 m. Conversely, the minimum concentration at a given distance is recorded with a 200 mm gap in summer, with a concentration of 160 860 ppm at a distance of 12 m. Therefore, the recommended safe distance from the leakage site is 11 m for a 400 mm gap in winter and 12 m for a 200 mm gap in summer (Figure S18).

The assertion that the substance's output rate is the same is also supported by the graph of the maximum concentration against time and the approximate tangent of two graphs with gaps of 300 mm and 400 mm.

### *Comparison of Graphs of Blast Consequences for Various Scenarios*

Table S7 summarizes the blast outcomes in this study. According to the table, a maximum pressure wave of 18 bar is experienced at a distance of 374 m, while at a distance of 275 m, the pressure wave peaks at 19.7 bar. The faster arrival time of the maximum pressure wave in winter compared to summer can be attributed to stable weather conditions. Additionally, as the effective distance from the source of the accident increases, the pressure wave diminishes. It is noted that the maximum pressure wave decreases as the distance from the blast site increases, particularly in summer.

In winter, the maximum pressure wave of 19.7 bar occurs at a distance of 473 m from the pipeline, within a 300 mm gap. Similarly, in summer, the maximum pressure wave is observed at a distance of 520 m with the same pressure level of 19.7 bar. Despite the difference in distance, the magnitude of the pressure wave remains consistent between summer and winter for both 300 mm and 400 mm gaps. This variation in distance is influenced by environmental temperature conditions, expansion, and contraction, resulting in changes in the pressure wave profile.

Table S7 indicates that for gaps of 200, 300, and 400 mm during various summer and winter periods, the maximum pressure wave remains consistent at 19.7 bar. However, for gaps of 200 mm during summer, the maximum pressure wave is slightly lower at 18 bar. These findings suggest that a gap of 400 mm allows for a maximum safe distance of 566 m from the leakage site following an explosion. Based on the worst-case scenario depicted in the graph, it is possible to align roads and residential areas with safety standards. Additionally, the graph provides valuable insights for responding to emergency situations. Therefore, individuals are advised to maintain a distance of up to 950 m in the event of a pipeline gap, as they may be exposed to pressure waves up to that distance (Figure S19).

### *Fire Graph Comparison for Various Scenarios*

The research findings indicate that the maximum safe distance following a leak is 85 m from the accident site.

This aligns with fire research findings, which indicate that the maximum radiation level of 350 kW/m² occurs during winter for gaps of 300 and 400 mm. Interestingly, the maximum radiation level for the 200 mm gap is lower, as observed by comparing the maximum radiation levels across the 200, 300, and 400 mm gaps. However, the minimal difference between the 300 mm and 400 mm gaps may be attributed to an identical material output rate (Figure S20).

The findings of this research regarding fire indicate that the maximum radiation level is 350 kW/m², occurring during winter for gaps of 300 and 400 mm. Consequently, the maximum safe distance following a leak is determined to be 85 m from the accident site. Utilizing the PHAST software, this research enables the identification of potential risks and the investigation of their consequences, allowing for the development of response plans to mitigate or control outcomes such as fire, explosion, substance release, and other accidents, thereby preventing unplanned events that may lead to equipment breakdown and harm to individuals. Moreover, comparing the risk assessment outcomes of this company with studies conducted in other companies at the national or international level reveals close similarities. For instance, in a study conducted by Motamedzadeh et al[31] in 2016 on the oil pipeline of Kermanshah and Sanandaj using the Kenneth Molbayer method, high-priority risks were identified, including third-party damage, corrosion, design flaws, incorrect vectoring for profit, and leakage. Similarly, in another study titled "Quantitative and Qualitative Risk Assessment of Iran's Oil Transmission Pipelines" by Izadi and Chavoshian[32], risks such as pressure differences leading to line rupture, inability to procure parts due to sanctions, pipeline failure due to wear and tear, rupture or cracking of the line due to natural events like landslides and flooding, and rupture of the line in rivers were identified as high-priority risks, mirroring the results of this research.

## Conclusion

High-priority risks were identified in this study based on available documents from the Maron Oil and Gas Exploitation Company and the risk assessment conducted on the pipeline under study. The FMEA method risk assessment revealed that operations involving welding, sandblasting, pipeline pressure testing, repair operations, and special incidents had the highest risk priority. Furthermore, the qualitative risk assessment of the studied pipeline highlighted human intervention, corrosion, design flaws, installation and operation errors, and natural disasters as the four primary threats and risk factors for the main 36-inch pipeline. Consequently, all these categories assign a high-risk priority due to the severity of the consequences of threats in the investigated section of the pipeline near the river. There are consistent and identical findings in both types of risk assessment, based on the currently available information. Additionally, significant similarities and overlaps exist between the risk assessment findings of this company and those of other companies that have conducted pipeline investigations on a national or international scale.

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### Author Contributions

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There is no conflict of interest between the authors and others.

### Ethical Approval

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### Supplementary File

Supplementary file contains Tables S1-S7 and Figures S1-S20

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